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SENTRE AND TREND ATTENUATING SYSTEMS

Final Report

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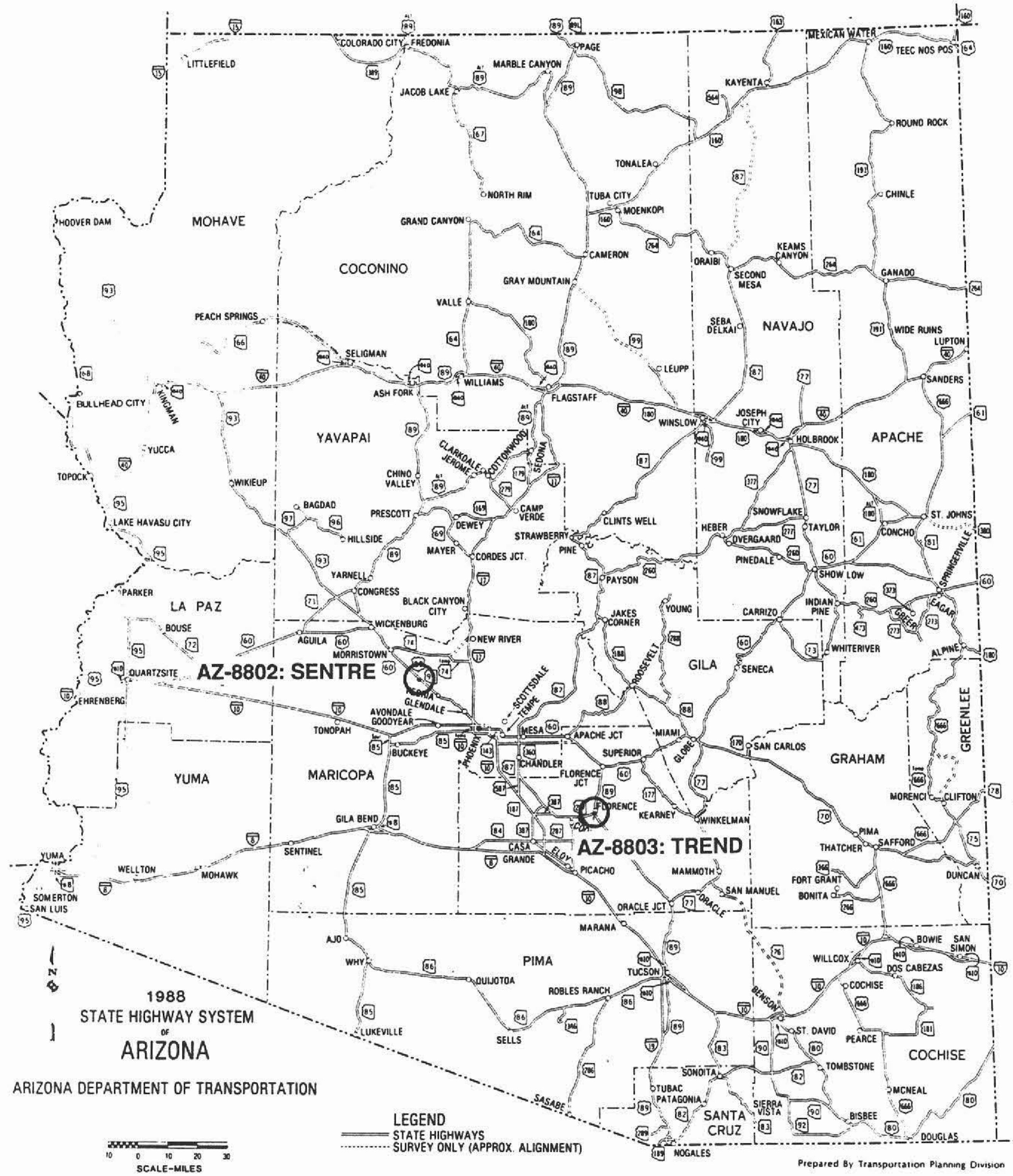

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16. Abstract

The objective of this study was to construct SENTRE and TREND attenuator systems and evaluate their in-service performance as set forth in NCHRP-230 for a period of two years. The evaluation was conducted as part of ADOT's New Product Evaluation Program. Both of the systems had performed satisfactorily in full scale crash testing conducted during other research efforts, and were designated as experimental by the FHWA at the onset of the study.

Four SENTRE end treatments were installed, one downstream and one upstream on both sides of a single bridge, as part of ADOT construction project HES-02202(33)P. Likewise, four TREND end treatments were installed, one downstream and one upstream on both sides of a single bridge, as part of ADOT construction project F-081-1(2). Both of these bridges extend over canals. The canals have parallel utility roads, and access to these roads precludes the full development of the length-of-need (LON) required with the use of guardrail. Following construction, the in-service performance was assessed from accident and maintenance cost records.

The systems were constructed without major difficulty, the TREND was completed and operational November 3, 1988, and the SENTRE was operational December 22, 1988. During the evaluation period the SENTRE was hit twice and the TREND was hit once. None of the impacts lent themselves to a safety performance evaluation of the attenuators, however, each of these hits required repair and replacement parts for the attenuators.

The repair process was found to be simple and in each case was performed without difficulty. However, the delivery time for replacement parts far exceeded EASI's claim of 48 hours. Delivery times ranged from two weeks to 37 days. The ATRC has recommended stockpiling spare attenuator parts in proximity to the attenuators for their timely repair. Further monitoring of the TREND is recommended until it is judged operational by the FHWA.

17. Key Words

Attenuator, End Treatment, Transition, End Terminal, Attenuating System, SENTRE, TREND, Guardrail, Bridge Rail, Traffic Barrier, Appurtenance.

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INTRODUCTION

This final report is the result of a product evaluation effort performed by the Arizona Transportation Research Center (ATRC) under a Federal Highways Administration (FHWA) approved workplan. The project was initiated and the construction project designed by the Highway Plans section of the Arizona Department of Transportation (ADOT).

SENTRE and TREND are proprietary names for attenuating end treatments; SENTRE is a guardrail end treatment, and TREND is a rigid barrier end treatment. They are manufactured and distributed by Energy Absorption Systems, Inc. (EASI).

Problem Statement

There are some instances where the geometry of certain facilities precludes full longitudinal barrier length protection of roadside hazards. This length, referred to as the length-of-need (LON), generally consists of a standard guardrail section with an end terminal. A situation common in Arizona where the full LON is often not met is the case where a bridge spans a canal. These bridges typically include longitudinal concrete rails, constituting a rigid roadside hazard. The LON in these instances is several hundred feet. Because it is necessary to maintain access to the utility roads along the canals, the full LON cannot be attained. Figure 1 illustrates the proximity of a canal utility road to a canal bridge. Figure 2 shows a similar bridge with full LON requirements met.

Figure 1 Canal and Utility Road.

Figure 2 Bridge with Full LON.

ADOT Standard End Treatments

The Arizona Department of Transportation (ADOT) commonly uses two standard end treatments for rigid roadside hazards. These are the Breakaway Cable Terminal (BCT), shown in Figure 3, and the Standard Attenuator Assembly, shown in Figure 4. The BCT is a guardrail end treatment with an anchored cable designed to redirect a vehicle upon lateral impact. The Standard Attenuator Assembly incorporates BCT features and also provides additional attenuating protection for end-on collisions. ADOT typical details for each of these barrier end treatments are included as Appendix B of this report.

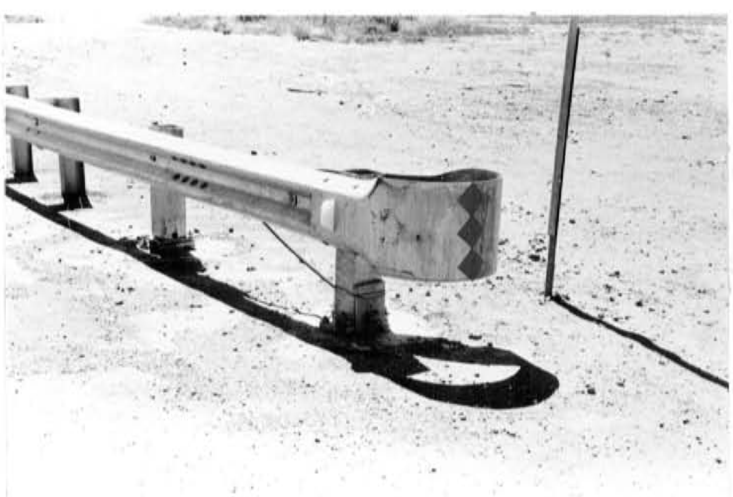

Figure 3 A Breakaway Cable Terminal (BCT).

Figure 4 An ADOT Standard Attenuator Assembly.

Traffic Barrier Performance Criteria

The safety performance criteria of longitudinal traffic barriers and other highway appurtenances are presented in the National Cooperative Highway Research Program Report Number 230 (NCHRP-230)[1]. The report states that although the safety performance cannot be measured directly, it can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision. A traffic barrier that performs satisfactorily is one that either stops or redirects the vehicle while maintaining the following performance goals:

1. Detached elements, fragments, or other debris from the appurtenance must not penetrate the passenger compartment of the impacting vehicle or present undue hazard to other traffic.

2. The vehicle should remain upright and decelerate in such a manner as to avoid occupant injury.

3. After collision, the vehicle trajectory and final stopping position should intrude a minimum distance, if at all, into adjacent or opposing traffic lanes.

The performance criteria here stated are first judged on the basis of monitored crash test results. Following successful crash tests, the final stage of development of highway appurtenances is an in-service evaluation. The purpose of the **in-service evaluation** is to determine the manner in which the appurtenance performs during a broad range of collision, environmental, operational, and maintenance situations for typical site and traffic conditions. These evaluations are executed with the realization that in some instances, unforeseen combinations of environmental and impact factors can defeat or degrade the safety performance of a traffic barrier.

The AASHTO *Guide For Selecting, Locating and Designing Traffic Barriers*[2] classifies the development of traffic barrier systems into three categories: 1) Operational; a barrier system which has performed satisfactorily in crash tests and in field evaluations. 2) Experimental; a barrier system which has performed satisfactorily in crash tests, but for which there has yet to be sufficient in-service field evaluations. 3) R & D; a barrier system for which there has not been sufficient crash tests or field evaluations to draw a performance conclusion. When an agency receives federal funding for the construction of a traffic barrier system classified as experimental by the FHWA, that agency must agree to monitor and report on the in-service performance of the barrier for a designated period of time. The performance data obtained is used in conjunction with similar data provided by other projects nationwide by the FHWA to determine if the barrier system will be upgraded to operational.

The SENTRE and TREND Systems

If an agency concentrates on the rigid bridge rail as the primary roadside hazard, a solution to maintaining close quartered utility road access is a short longitudinal barrier installed at the end of the bridge. One manufacturer, Energy Absorption Systems, Inc. has developed two barrier systems which are short in length and are claimed to meet NCHRP-230 crash test performance goals. These systems are the TRansition END treatment (TREND) and the Safety barrier ENd TREatment (SENTRE). The systems are similar, differing in that SENTRE is designed as a guardrail end treatment and TREND is designed as a rigid barrier end treatment. SENTRE has five telescoping thrie beam panels supported on vertical posts set on slip bases. The slip bases are actually two plates welded together with the bottom plates mounted on concrete footings or a concrete pad. TREND has six such thrie beam panels and posts. Each system consists of a redirecting cable tightened to 100 foot-pounds torque, and six sand boxes; four filled with 100 pounds of sand and two containing 150 pounds of sand. The cable redirects vehicles from the roadside hazard, and the sand boxes attenuate the impact. Manufacturer's drawings of SENTRE and TREND are provided in Figures 5 and 6, respectively. A more detailed description of the systems as provided by the manufacturer is included in Appendix C of this report.

Energy Absorption Systems, Inc. has presented certification reports supporting claims that SENTRE and TREND meet the crash test performance requirements of NCHRP-230[3,4]. The FHWA, concurring, but lacking sufficient in-service performance data, had classified SENTRE and TREND as experimental barrier systems at the onset of this project. In April, 1989, SENTRE was upgraded to an operational barrier system by the FHWA. As of June, 1991 the TREND remains classified as experimental.

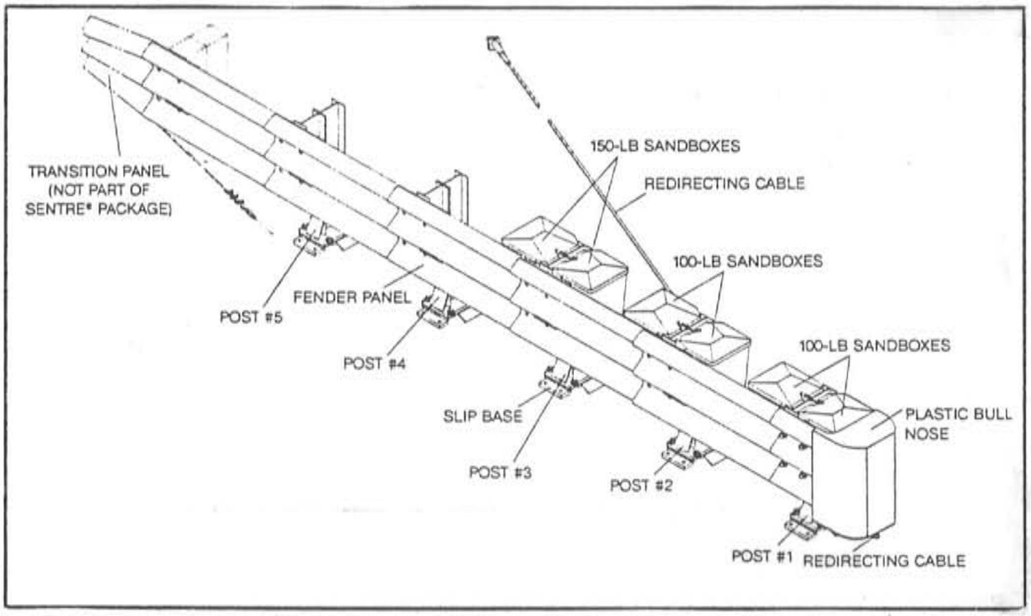

Figure 5 SENTRE End Treatment.

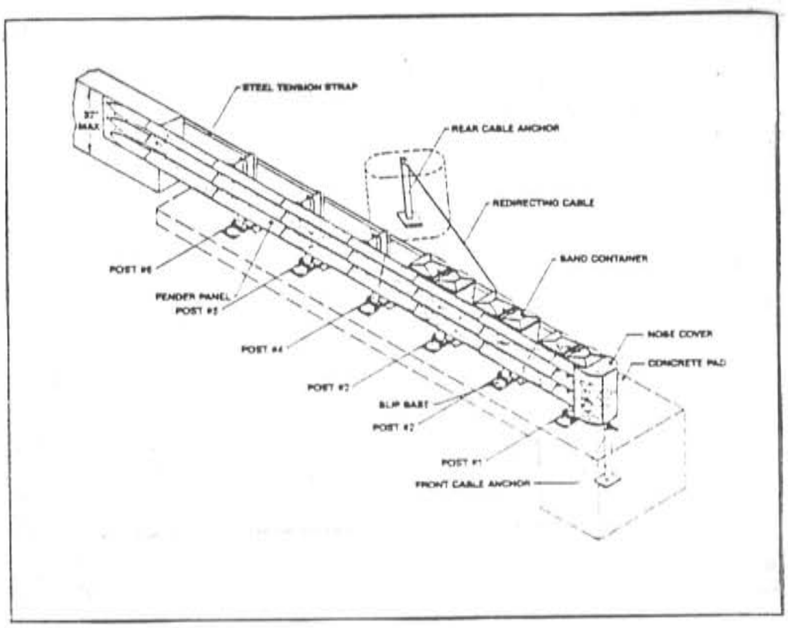

Figure 6 TREND End Treatment.

OBJECTIVES

In-Service Performance Evaluation

The purpose of this project was to monitor and evaluate the in-service performance of the SENTRE and TREND end treatments, based on NCHRP-230. In-service evaluations are undergone with the objective of discovering what problems, if any, may arise with the construction, operation, and maintenance of safety devices, under a variety of circumstances at a typical site. These problems may not have been evident during controlled crash tests. If such problems are discovered, modifications to the devices may be proposed to improve the devices and/or lower costs prior to widespread use.

The SENTRE and TREND systems were installed and monitored in accordance with the FHWA approved workplan included in this report as Appendix A.

LOCATION OF PROJECTS

Originally, two sites were selected for the placement of TREND attenuating systems. The sites were selected on the basis of design needs at both locations. Research needs were not considered. It was later discovered that the steel bridge rail plan for one of the selected locations precluded installation of the TREND, but that it was suitable for a SENTRE installation. As a result, a second experimental project was initiated for the SENTRE. The SENTRE installation is identified as Experimental Project AZ-8802, and the TREND installation is identified as Experimental Project AZ-8803.

AZ-8802: SENTRE End Treatment Field Installation

Four SENTRE end treatments were installed, one at each corner of a single bridge, as part of ADOT construction project HES-02202(33)P. This bridge is located at approximately milepost 138.0 on US 60, the Wickenburg-Phoenix Highway, and crosses the Beardsley Canal. The posted speed limit at this location is 55 mph, and the site is in ADOT District 3. The project involved removing existing concrete curb, and replacing it with a new concrete curb supporting a tubular thrie beam bridge rail assembly. The original 40' width of clear roadway, consisting of two 12' lanes and two 8' shoulders, was maintained. The highway is flat in the vicinity of the project and the view is unobstructed. Figure 7 is a photo of the project site before construction.

The 1989 design ADT for this two-lane highway is 8,309 vehicles[5]. Sixty-two percent of these are passenger type vehicles[5]. During the sixteen year period before the onset of this project (1973-1988) there were 13 accidents involving collisions with the existing bridge rail[6]. Six of those were injury accidents. The number of accidents recorded divided by the number of years of the accident record yields a probability of collision with the bridge rail of 0.813 for any one year. The corresponding probability of at least one collision during the two year evaluation period is 0.965. These probabilities are based solely on the number of previous incidents and no provision for changing traffic conditions has been made.

Figure 7 AZ-8802: SENTRE End Treatment Installation Site Prior to Construction.

AZ-8803: TREND End Treatment Field Installation

Four TREND end treatments were installed, one at each corner of a single bridge, as part of ADOT construction project F-081-1(2). This bridge is located at approximately milepost 132.6 on US 89, the Florence Highway, and spans the Casa Grande Canal. This location falls within ADOT District 2. The project included removal of the existing concrete curb and attached W-section bridge rail, and replacing them with a new concrete parapet wall type bridge rail. The original 40' width of clear roadway, consisting of two 12' lanes and two 8' shoulders, was maintained. The canal bridge is located just north of the intersection of US 89 and SR 287, and the posted speed limit is 35 mph. Figure 8 is a photo of the project site before construction.

Figure 8 AZ-8803: TREND End Treatment Installation Site Prior to Construction.

The 1989 design ADT for this two-lane highway in the vicinity is 2,565 vehicles[5]. Fifty-seven percent of these are passenger type vehicles[5]. During the sixteen year period prior to the onset of this project (1973 to 1988) there were three reported accidents at the canal bridge[6]. Based on this accident history the probability of an accident at the canal bridge is 0.188 for any one year, and the corresponding probability of at least one accident during the two year evaluation period is 0.340. The probabilities presented here are based solely on the number of occurrences in the last 16 years and no provision for changing traffic conditions has been made.

CONSTRUCTION

Construction of the SENTRE system took place on December 19 and 21, 1988 and was performed by Klondyke Inc. The system was operational on December 21, 1988. The TREND system was installed on November 3, 1988 and was performed by Nesbitt Contracting Co. The system was operational on November 3, 1988.

The construction procedures for the SENTRE and TREND were similar. The forthcoming description applies to both systems unless otherwise stated. Plans for the SENTRE and TREND projects are included as Appendix D and E of this report.

Procedure

A manufacturer's drawing of the assembly of post 2 is included as Figure 9 to further aid in the description of the assembly of the SENTRE and TREND systems.

The SENTRE and TREND systems were constructed with concrete footings. The concrete used was Class S concrete with f_c= 4000 psi. The TREND footing is 21' long, 4' wide, and 8" deep. The footing is increased to 3' deep in the 3' of the footing furthermost from the bridge rail to accommodate the embedment of the redirecting cable anchor. The SENTRE footing is the same except for its length. The SENTRE footing is only 17.5' long as SENTRE only has five posts rather than TREND's six.

The footings for the SENTRE system were poured on September 19, 1988 and had a 28 day compressive strength of 4829 psi. The footings for the TREND system were poured on October 17, 1988 and had a 28 day compressive strength of 5839 psi.

The bottom plate of each of the slip bases is mounted on the concrete footings with six 7.5" long, 3/4" diameter bolts. The SENTRE's five base plates were spaced at 36" on center and the TREND's six base plates at 37.5" on center. The bolts were epoxied into the holes with epoxy included as part of both the SENTRE and TREND packages.

The upper plate of the slip base is mounted on the lower plate with four 2.5" long 3/4" diameter bolts. This is illustrated in Figure 10.

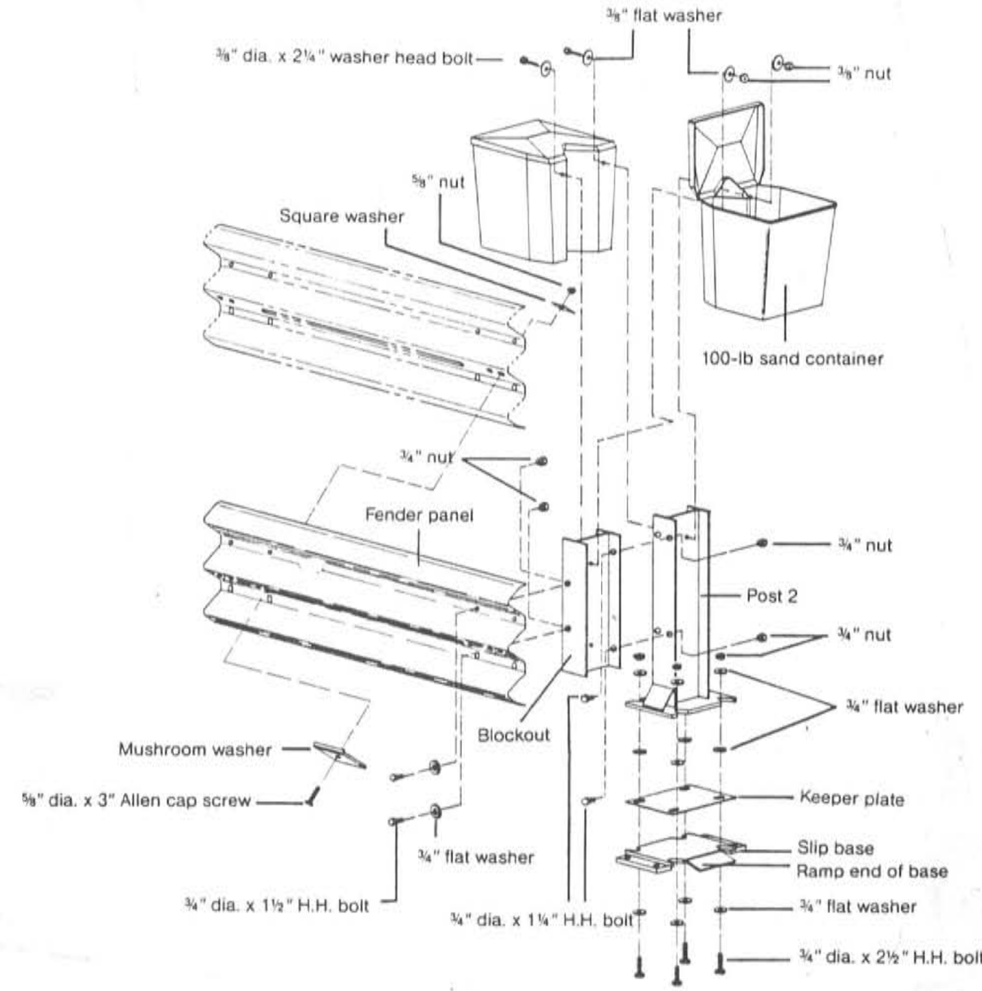

Figure 9 Assembly of SENTRE and TREND Post 2.

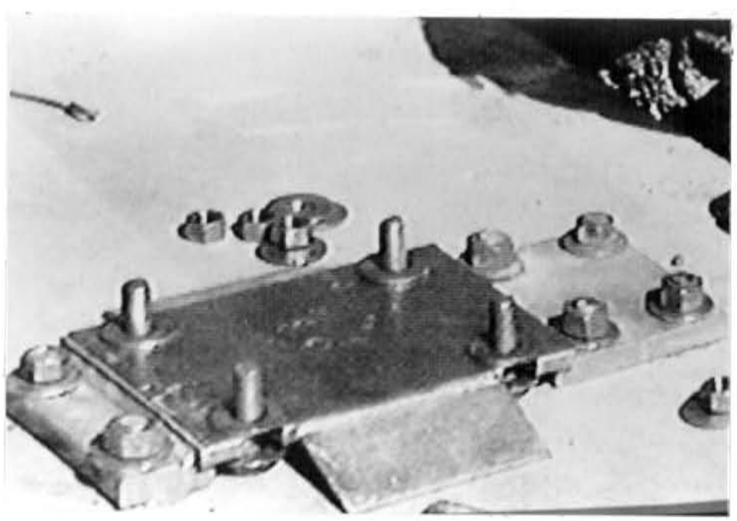

Figure 10 Base Plate Assembly.

The support posts of the SENTRE and TREND consist of 32" long W6.5x9 A36 steel posts with a slotted 1/2" thick steel plate welded to the end. The support posts are bolted to the slip bases at these plates as shown in Figure 11. The bolts are tightened to manufacturers specification of 60 ft-lbs torque.

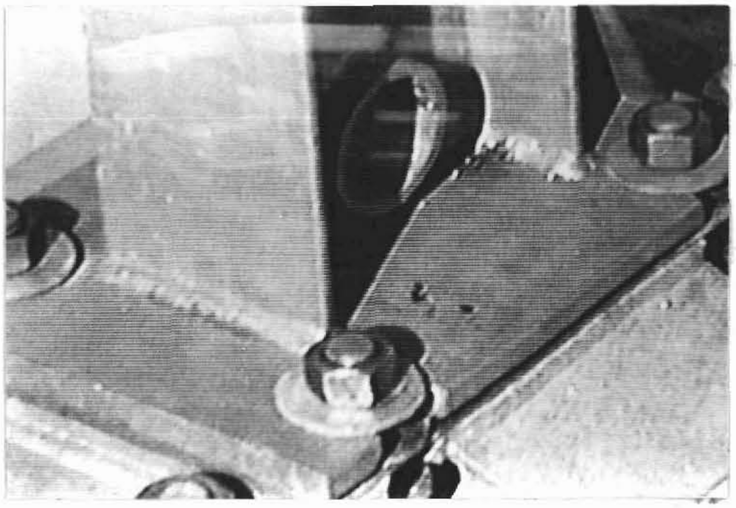

Figure 11 Post Attached To Base Plate.

A 21" W6.5x9 steel blockout is attached to each post. The systems' thrie beam panels are fixed to these blockouts. The panels are connected together by a mushroom bolt in horizontal slots and overlap such that the overhang is away from the free end of the system.

The three posts furthest from the bridge (posts labeled 1, 2, and 3 in figures 5 and 6) have sand containers attached. Posts 1 and 2 each support two containers, both designed to hold 100 lbs. of sand. Post 3 supports two containers, each with 150 lbs. of sand. The containers were filled with sand and the lids snapped shut.

A 23' steel redirecting cable goes through a hole in post 1 and is anchored at the front of the system. The other end is fastened at a rear anchor location forming an angle of approximately 25 degrees with the roadway. The cable is tightened to a specified 100 ft-lbs torque. The cable and anchors are shown in Figures 12 and 13.

A 20' transition between the SENTRE and the tubular thrie beam bridge rail was placed upon seven posts driven into the ground spaced at 3' O.C.. The posts are the same type of post as used in the SENTRE system. The end panel of the SENTRE is tied to the transition. As the transition is also of thrie beam configuration, it is important to insure the concave component of the SENTRE and transition thrie beams are concurrent. This special requirement was not foreseen in the construction of this installation. The upstream thrie beam matched the SENTRE panels, but the downstream splice was of opposite concavity to the SENTRE panels. The problem required a special downstream splice. The special downstream splice and an upstream splice are shown in Figures 14 and 15.

Figure 12 Front Anchor of Redirecting Cable.

Figure 13 Rear Anchor of Redirection Cable.

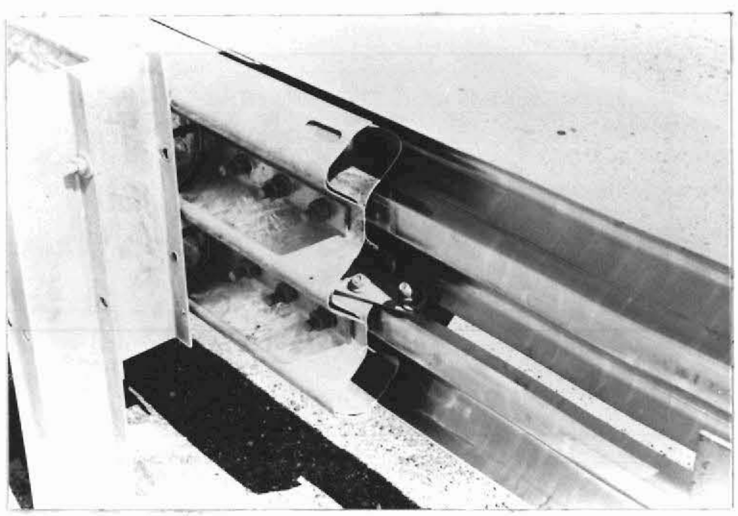

Figure 14 Special Downstream Splice.

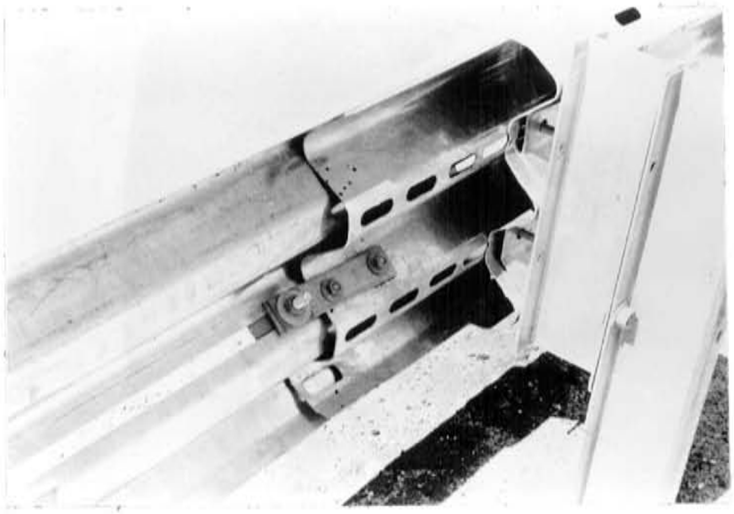

Figure 15 Proper Splice.

The TREND system is attached directly to the concrete parapet wall of the bridge with two 3/4" diameter bolts (Figure 16). The steel backstrap of the TREND is bolted to the back of the concrete wall as shown in Figure 17.

Figure 16 TREND Attached to Front of Concrete Parapet Wall.

Figure 17 TREND Backstrap Attachment to Concrete Parapet Wall.

The completed SENTRE and TREND systems are shown in Figures 18 and 19. Each unit required approximately 12 man-hours to construct, not including the time for the construction of the concrete footings.

Figure 18 Completed SENTRE System.

Figure 19 Completed TREND System.

ECONOMICS

Construction Cost Comparison

The bid price for installing the SENTRE system at the Beardsley Canal bridge was $7421 for each of the four units. The TREND was completed for a bid price of $8600 for each of the four units. The bids included traffic control, however the costs still greatly exceeded SENTRE and TREND component costs of $2500 and concrete costs of an estimated $400.

In comparison, the lone ADOT Standard Attenuator constructed in 1987 had an average of the three lowest bids of $3558[7]. A single BCT, in those instances where four where bid upon, carried an average 1988 bid cost of $692[8]. The cost of guardrail between 200' and 1000' had an average 1988 bid cost of $12.85 per linear foot[8]. Considering the calculated sufficient LON of 293'[9], the sum of these 1988 bid costs leads to an estimate of $4458 per BCT with appropriate LON guardrail. In the case of guardrail and BCT however, the access road would have to be realigned, perhaps adding considerable expense.

Maintenance Costs

Maintenance costs of the SENTRE and TREND systems came solely in the form of repair of damage to the attenuators. In 1989 ADOT spent $1205 on the SENTRE installation and $540 on the TREND. There was no repair work done on either system during 1990. The extent of the work done and the itemized repair costs is presented within the incidents described below. Labor costs associated with the incidents are reported as they were calculated at the time by the maintenance crews involved. They are the sum of the wages of the men doing the repair work for the time taken to complete the repair. ADOT has since incorporated a method of determining labor costs including insurance and other benefits. A round figure for repair work calculated in this manner is $19 per hour per man.

INCIDENTS

The monitoring period extended from the time of installation; November 3, 1988 for the TREND system, and December 22, 1988 for the SENTRE system, until and including January, 1991. During that time period, the attenuators were subject to monthly inspections by ADOT maintenance personnel. The inspection consisted of identification of any vehicle or non-vehicle induced damage, checking the nose covers, sand containers, and redirection cables for proper placement, and identification of any evidence of vehicular near misses. District 2 maintenance personnel inspected the TREND system and District 3 maintenance personnel inspected the SENTRE system. Additionally, any damage to the attenuators was reported upon discovery.

The SENTRE System

During the monitoring period the SENTRE system over the Beardsley Canal was twice subject to damage requiring repair or replacement, affecting three of the attenuators.

The first SENTRE impact damage was on the northwest attenuator and discovered on August 22, 1989. There were no witnesses to the impact and no accident report was filed. During that period of time a Maricopa County road construction project was underway in the immediate vicinity and US 60 was temporarily realigned just west of the attenuators. Because of the construction, there was considerable heavy equipment and semi-truck traffic. There were black tire marks on the top and bottom of the damaged attenuator suggesting that the impacting vehicle may have been one of these large construction vehicles. Because of the extent of the damage, it was uncertain if the attenuator would perform as designed upon a subsequent impact, and the damaged attenuator was repaired. A photograph of the damaged attenuator is shown in Figure 20.

Figure 20 Damaged SENTRE Attenuator.

An itemized list of the replaced components and associated costs is shown in Table 1. The unit prices are those provided by EASI at the time of replacement.

DESCRIPTION	UNIT PRICE	QUANTITY	COST
Post 1	$73.00	1	$73.00
Post 2	65.00	1	65.00
Post 3	50.00	1	50.00
Blockout	16.00	2	32.00
Nose	50.00	1	50.00
100# Sand Box	35.00	2	70.00
Tax and Shipping			50.92
Labor			215.08
Total			$606.00

Table 1 Itemized List of Replacement Costs (First SENTRE Hit).

The thrie beam fender panel was also damaged by this first impact, suffering a slight crimp. Because of the minor amount of damaged sustained, and the substantial cost of replacement ($227), it was decided that the crimp would be pounded out, as opposed to replacing the panel.

Energy Absorption Systems, Inc. had claimed that only 48 hours were required to receive replacement parts from the time of ordering. This was not the case. The replacement parts of Table 1 were ordered on August 31, 1989 and not received by ADOT until September 14, 1989. As a result, the attenuator was out of service for over three weeks.

According to the work report filed by District 3 Maintenance Division, the actual repair process was simple and was carried out by three men working a total of eight hours each. The total cost of the repair including parts, labor, shipping and tax came to $606.

The second impact was discovered September 26, 1989. The Maricopa county road construction project was still in progress on US 60, and the highway was still temporarily realigned beginning just west of the SENTRE attenuators. As with the first incident, there was a significant amount of heavy construction equipment and semi-truck traffic. Two of the attenuators were discovered to be damaged; the southwest more severely than the northwest. At the southwest attenuator, marks in the soil and impact induced spalling of the SENTRE's concrete footing served as evidence that a front end loader or scraper had scraped its bucket or blade all the way up to the attenuator. The southwest attenuator was obviously impacted by a large construction vehicle, possibly the same vehicle that had left the scrape marks in the soil. This attenuator was impacted in the direction of travel and telescoping of the panels did occur. The mushroom bolt attached to panel 1 was free to slide as designed. A photograph of the damaged system is included as Figure 21.

Figure 21 Damaged Southwest SENTRE Attenuator.

The northwest attenuator was hit on the nose longitudinally. Post 1 was slightly twisted but judged operational. An itemized list of the items replaced and associated 1989 costs is given in Table 2.

DESCRIPTION	UNIT PRICE	QUANTITY	COST
Post 1 (SW)	$73.00	1	$73.00
Post 2 (SW)	65.00	1	65.00
Blockout (SW)	16.00	2	32.00
Nose (SW)	50.00	1	50.00
Nose (NW)	50.00	1	50.00
100# Sand Cont. (SW)	35.00	2	70.00
Tax and Shipping			23.00
Labor			236.80
Total			$599.80

Table 2 Itemized List of Replacement Costs (Second SENTRE Hit).

Once again EASI's claim of requiring only 48 hours from order to delivery of replacement parts proved not to be the case. As a result the attenuator was out of service for nearly a month.

Again the repair was simple. A three-man maintenance crew worked a combined total of 24 man-hours to complete the repair. The total cost to ADOT including parts, labor, shipping, and tax came to $600.

The TREND System

During the monitoring period the TREND system spanning the Casa Grande Canal was hit only once. However, vandals have caused minor damage to the system several times.

The vehicle damage to the TREND system was discovered on January 30, 1989. There were no witnesses to the impact. The southwest attenuator was hit from the side, suggesting the vehicle was intent on travelling west on the dirt access road along the canal. Photographs of the damaged TREND system are included as Figures 22 and 23.

Figure 22 Damaged TREND Attenuator.

Figure 23 Damaged TREND Attenuator.

The damaged TREND system was no longer parallel with the roadway, and it's future performance was doubtful. As such, Energy Absorption Systems, Inc. was contacted for replacement parts and the system was repaired. Table 3 shows an itemized list of components replaced and associated costs from EASI at the time of replacement.

DESCRIPTION	UNIT PRICE	QUANTITY	COST
Post 1	$73.00	1	$ 73.00
Post 2	65.00	2	130.00
3/4" Bolt, 2.5"	0.42	4	1.68
3/4" Washer	0.25	4	1.00
3/4" Nut	0.47	4	1.88
Blockout	16.00	2	32.00
Nose	50.00	1	50.00
100# Sand Cont.	35.00	2	70.00
Tension Strap, 79"	11.00	1	11.00
Tax and Shipping			56.90
Labor			112.97
Total			$540.41

Table 3 Itemized List of Components Replaced (TREND Hit).

The thrie beam fender panel was also slightly dented. The minor amount of damage sustained combined with the substantial replacement cost ($227) resulted in a decision not to replace the component.

As with the SENTRE system, EASI could not maintain their claim of only 48 hours order-to-delivery time. Parts ordered on February 9 were not received by ADOT until March 3. As a result, the attenuator was out of service for 37 days.

The repair was performed by an ADOT maintenance crew. The crew dismantled and removed the damaged components, and replaced them with the new parts. The crew of three men worked 4 hours, for a total of 12 man-hours, to complete the job. The labor cost was $113, bringing the total cost or repair including parts, labor, tax, and shipping to $540.

The extent of the damage to the TREND caused by vandals was the unfastening and removal of the plastic lids of the sand containers. This happened on several occasions and was corrected by merely re-fastening the lid by the inspecting maintenance personnel.

CONCLUSIONS

Construction

The initial construction of the SENTRE and TREND was performed without difficulty. A major concern expressed by ADOT District 1, District 2, District 3, and Highway Plans is the overlapping of downstream thrie beam panels. The panels are overlapped such that telescoping will occur upon a head-on impact. Longitudinal impacts are the source of concern. On the upstream installation of the SENTRE and TREND systems, the overlapping panels do not pose a problem. However, on the downstream installation the overlaps leave exposed edge sections. The concern lies with a vehicle snagging on these overhanging panels during the course of a longitudinal hit, encountering a more hazardous situation than a similar impact with the panels overlapping away from traffic. An illustration of the panel overlapping is presented as Figure 24. The upstream panels are illustrated in Figure 25.

Figure 24 Overlapping Panels on Downstream Attenuator.

Figure 25 Overlapping Panels on Upstream Attenuator.

In-Service Performance

During the course of the evaluation period three of the SENTRE and one of the TREND attenuators had been damaged severely enough to require repair. All of these impacts appeared to have been the result of heavy construction equipment. Because in each of the incidents the vehicle did not remain at the site, it is inappropriate to draw any conclusions on the safety performance of the attenuators per NCHRP-230. Due to the lack of any reports of the collisions, it is reasonable to assume that in all instances the occupants of the vehicle were not injured.

Although the impacts did not lend themselves to a safety performance evaluation of the SENTRE and TREND, in-service performance information of the systems was provided. After each of the impacts, the spare parts required for repair were ordered from Energy Absorption Systems, Inc. promptly. In every instance it took within a range of two weeks to 37 days for the replacement parts to be received by ADOT. EASI had claimed a maximum of 48 hours order-to-delivery time for replacement parts.

In each case, the repair of the SENTRE and TREND systems was simple, and completed within a day by a three man maintenance crew.

Future Considerations

As a result of the repeated excessive delay in delivery of replacement components for the SENTRE and TREND, the Arizona Transportation Research Center (ATRC), working with EASI representatives, had recommended that ADOT stockpile one set of specific spare attenuator parts at a cost of approximately $1079. An itemized list of the parts recommended by the ATRC is shown in Table 4.

DESCRIPTION	UNIT PRICE	QUANTITY	COST
Post 1	$73.00	2	$ 146.00
Post 2	65.00	2	130.00
Post 3	50.00	3	150.00
Blockout	16.00	6	96.00
Fender Panel	227.00	1	227.00
100# Sand Cont.	35.00	4	140.00
150# Sand Cont.	45.00	2	90.00
Nose	50.00	2	100.00
Total			$1079.00

Table 4 ATRC Recommended Stockpiled Parts.

In May of 1990, ADOT District 3 Maintenance purchased the spare parts of Table 4 for maintenance of the SENTRE system. The total cost after tax and delivery came to $1174. There have been no incidents requiring repair of the attenuator system since the acquisition of the spare parts. ADOT District 2 thusfar has not purchased any spare parts in advance for the TREND system.

A concern brought to light by this experimental project, and subsequent stockpiling of parts, is the problem with the proliferation of numerous end treatments. A number of different end treatments with non-interchangeable components will require substantially more warehouse space than only one or two acceptable end treatments.

RECOMMENDATIONS

Based on the experiences of the field installations of SENTRE and TREND in Arizona, the following recommendations are presented:

1. Agencies should stockpile replacement parts for highway appurtenances that may require repair. The timely repair or replacement of attenuators and other appurtenances is crucial from both a safety and liability point of view.

2. Agencies should utilize similar appurtenances in geographical proximity to one another. The reason for this is to expedite repair by allowing stockpiled parts to be kept nearby, rather than at a central location. If two or more types of appurtenances without interchangeable parts are close together, the storage space and capital investment needed for stockpiled parts will be significantly increased.

3. Due to the nature of the impacts encountered, the TREND should be subject to further monitoring until such a time that the FHWA has developed sufficient database to determine if the system should be upgraded to operational. The SENTRE was upgraded to operational in April, 1989.

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